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ABITIBI CANYON GS - MAIN DAM SELECTION AND INSTALLATION OF DEFORMATION MONITORING INSTRUMENTS

C.B.H. Cragg

Deformation monitoring is considered an important indicator of safe dam performance yet it is lacking in many of Ontario Hydro's large dams. Abitibi Canyon is the highest water retaining structure in Ontario yet it had no instrumentation for monitoring deformations. As part of a program to upgrade the instrumentation of the Corporation's dams,a review was made of the methods available for monitoring deformations and a system of normal and inverse pendulums was selected for use at Abitibi Canyon GS. This report documents the deformation monitoring equipment considered in the review, the installation of the pendulums at Abitibi Canyon GS and the initial instrument readings.

1.0 INTRODUCTION

Civil Research was retained by Civil Works to evaluate deformation monitoring systems and recommend a system for Abitibi Canyon GS. Civil Research was later requested to install the selected instruments at Abitibi Canyon main dam.

When constructed in 1933 to a height of 347 ft, Abitibi Canyon was the highest dam in Canada. It retained this distinction until the W.A.C. Bennett Dam was built in 1967/1/. This structure was, appropriately, one of the first selected by Civil Works for monitoring improvement under a developing dam safety program. Instruments for monitoring uplift pressures on the main dam concrete structure and stability of the earth abutment areas were installed in 1983 by Geotechnical Engineering/2/. This study of deformation monitoring systems took place in mid-1984. The subsequent

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installation of instruments took place and was generally completed late in 1984. Detailed initial readings were taken early in 1985. Instrument selection, installation and initial monitoring results are described in this report.

2.0 DEFORMATION MONITORING SYSTEM SELECTION

Why Monitor Deformations?

While it is acknowledged that visual observations are the most important method for detecting deterioration of dams, deformation instruments are an important alternate and often a necessary supplement to the visual inspection process. If sufficiently sensitive instruments are used, deformation monitoring can detect cyclical and progressive movement trends prior to structural deterioration occurring which may be visually observed. Table I shows the relative frequency with which dam deterioration was first detected by various monitoring methods/3/. The frequency of first detection by direct observation is overstated in this table because, in many cases, it was the only monitoring method used for early warning. Deflection measurements detected deterioration a significant 130 times in the 1105 case studies reported/3/. Deformation measurement is thus an important tool in assessing dam safety. The following sections examine the most appropriate method for monitoring Ontario Hydro's concrete dams.

Selection Factors

In evaluating methods for deformation monitoring of concrete dams, the following interrelated factors were considered:

- accuracy of readings
- installation costs
- desired monitoring frequency
- monitoring costs
- personnel and equipment requirements for monitoring. These factors are discussed below.

Accuracy: Temperature change over the year produces cyclic deformations ranging from 0.1 to 0.2 inches at Stewartville GS and Rayner GS/4/. At Rayner GS, a gradual downstream tilting of 0.03 inches/year was detected. For a monitoring method to be effective in recognizing deterioration or abnormal behaviour at Abitibi Canyon GS, it should be capable of measuring the normal, temperature-induced deflections. Accordingly, an accuracy of 0.02 inches was sought in the deflection measuring system.

Cost: In terms of economics, both the initial installation costs and the costs of taking readings should be considered in selecting a monitoring method. A device that is more expensive to install but simple and inexpensive to monitor may be the most economic choice in the long term, particularly if frequent readings are desired. Frequent readings were desirable at Abitibi Canyon, at least for the first year or two, in order to determine normal behaviour and the most appropriate times for a reduced reading schedule.

Personnel: In terms of personnel, it was preferable that Regional staff be used for readings. The proximity of these people to the instrumentation makes them the most suitable for economic and frequent readings. However, the reading method and equipment selected must be consistent with their skills.

Methods Evaluated

The instrumentation methods considered for use at Abitibi Canyon were:

- surveying (triangulateration)
- inclinometer
- inverse pendulums

From the comparison of these methods in Table II, it may be seen that pendulums, while costing more to install, best meet the selection factor requirements for accuracy, reading simplicity and long term economy. Because they are located within the dam structures, pendulums offer access advantages over surveying for winter readings. Normal pendulums may take advantage of existing openings in the structure (eg construction joint drains or stairwells) for installation economy. Bedrock below the structure supporting inverse pendulums may be a more stable and reliable reference point than soil or rock slopes outside the structure supporting survey reference stations. Hydro Quebec has found pendulums to be their most reliable method of monitoring dams/8/.

This evaluation lead to the choice of normal and inverse pendulums for monitoring deformations at Abitibi Canyon GS. A recent ICOLD conference showed other countries have reached the same conclusion/9/.

3.0 INSTRUMENTS INSTALLED

The instruments installed at Abitibi Canyon GS consisted of two (2) inverse pendulums, two (2) normal pendulums and six (6) alignment survey points. Wire extensometers formed part of each pendulum assembly. Normal pendulums were hung in the 2 foot diameter vertical joint drains from deck to inspection tunnel level, at chainages 7+12 and 8+99.5. The inverse pendulums were located near the normal pendulum in the inspection tunnel and were drilled to a depth of about 50 feet below the tunnel level (see Figure 1). Figure 2 shows the plan location on the dam deck of the alignment survey pins and the normal pendulums. The normal pendulums form part of the alignment survey.

As the largest deflections were expected at the highest point of the dam, these locations for the pendulums were selected to capture these largest deflections, utilize the existing joint drains (for economy) and use relatively dry joint drains (for reading accuracy).

A schematic of the inverse and normal pendulums is shown in Figure 3. Both devices incorporate a stainless steel wire and an invar wire which are stretched from an anchorage point to a tensioning device. Weights or weights with lever arms apply tensions of about 25 pounds to the invar wires and stainless steel normal pendulum wires. Floats apply a tension of

about 45 pounds to the stainless steel inverse pendulum wires. Virtually all pendulum components were fabricated in stainless steel for long term corrosion resistance, using design drawings supplied by Hydro Quebec. These drawings are on file in Civil Research, if further instrument details are desired. The inverse pendulum anchor is connected to NQ drill rods grouted in an NX core hole drilled vertically (ideally within +/- 5 mm of plumb) beneath the inspection tunnel.

Stainless steel bolts anchored into the dam deck were used for the alignment survey points. A small diameter brass pin was inserted into the head of each 5/8 inch diameter bolt to allow accurate sighting.

4.0 INSTALLATION PROCEDURE

Transportation of drill equipment and supplies for the inverse pendulums was accomplished down the vertical joint drains or up the several ladders in the inspection tunnel. Fortunately the Kempe drill (Figure 4) was small enough to be lowered down the drains. The small dimensions of the inspection tunnel made working conditions quite difficult, especially where water supply and fire pipes installed in the tunnel further restricted the working space. Vertical alignment of the drill hole was measured with a weight (inserted in the wire line drill rods) and pendulum system after each 5 foot core run (Figures 5, 6, and 7). When the drill was expected to exceed 5 mm out of plumb in the next 5 foot coring run, alignment was restoredusing an eccentric pilot hole and reaming method as described in Appendix A. Figures 8 and 9 show the plumb measurements and the depths of corrections made in drilling the inverse pendulum holes. BW casing (2-3/8 inch ID) was grouted in these holes after drilling was completed. After the grout had set, the pendulum anchor, with wires attached, was coupled to the bottom of the casing and the upper tensioning devices. (The tensioning device supports are fastened to the inspection tunnel walls with bolts and concrete anchors). Figure 10 shows a completed inverse pendulum installation.

The top anchor points for the normal pendulums were supported on angle irons bolted to the construction joint drain concrete about six inches below the dam deck. Reading tables for these units were placed in the inspection tunnel at the same elevation as the inverse pendulum reading tables. A grating was constructed across the joint drain at tunnel floor level to support the oil filled dashpot for the pendulum and to permit safe access to the device for readings. The drains have insulated top covers to limit the ingress of water and dirt (eg winter sand) from the deck road and to limit formation of ice in the drain. Rainguards were installed in the drains to reduce the amount of water falling on the reading table and people taking readings.

Precise survey bullseye bubbles were mounted on all reading tables to detect misalignment caused by pedestrians in the tunnel.

5.0 MONITORING PROCEDURES AND RESULTS

The position of the pendulum wire is read relative to the posts of the reading table, using a digital depth micrometer. Readings are taken in all

four directions (upstream, downstream, left bank, right bank) to ensure an accurate determination of the wire's position. The sum of the upstream and downstream readings should equal the distance between the reference posts on the reading table, less the thickness of the pendulum wire, if the readings are done accurately. An "error" in this comparison of 0.01 inch is considered acceptable. These readings show the change in the horizontal position of pendulum reading tables with respect to the pendulum wire anchoring points. Appendix A details the procedure to be used in reading the pendulums and Appendix B shows examples of reading interpretation.

A profile of the inverse pendulum boreholes may be obtained by sliding an autocentering device (Figure 11) down the pendulum wire, stopping it at regular depth increments and measuring the position of the pendulum wire at the reading table. For more detail on this device, developed by Hydro Quebec, consult reference 10. Autocentering device readings were taken at the Abitibi Canyon inverse pendulums by Hydro Quebec personnel using their own instrument and 1 m depth spacings. Research is now equipped to perform these readings.

Should movement of the dam be detected in the future, repeat autocentering readings can detect the horizon where the movement occurred. Consideration should be given to repeating autocentering readings when comprehensive inspections are done.

Through the invar wire extensometer, the vertical position of the reading table is monitored relative to the wires anchoring point. Readings are taken by setting the digital depth incrometer vertically on the reading table over the pendulum wire hole and measuring down to the pointer (inverse pendulum) or cylinder (normal pendulum) attached to the invar wire.

Surveys of the deck pins were intended to use first order levelling and alignment monitoring techniques, similar to those used for turbogenerator monitoring. Table III lists the equipment employed for turbogenerator surveys. Survey results should endeavor to match the accuracy of the pendulum readings, ie 0.02 inch. These measures are intended to detect movement of different blocks of the dam relative to the top of the normal pendulums. Through the normal and inverse pendulum readings, all crest movements can be related to the assumed immobile inverse pendulum anchor points in the rock below the dam. Appendix A gives examples of pendulum reading interpretation.

Initial pendulum readings are recorded in Table IV. Initial autocentering device readings are documented in Table V. Initial elevations taken on the deck pins are summarized in Table VI. The initial alignment survey was performed by Civil Works personnel.

6.0 DISCUSSION

As these were the first inverse pendulums installed within Ontario Hydro dams, considerable learning was required to accomplish the work. This learning, when combined with the difficult access and unusually restricted

working space at this site, resulted in a lower productivity rate than might otherwise be expected. Subsequent inverse pendulum installations should proceed more quickly and produce vertical holes with less deviation.

The plant air supply was found to be an unreliable power source for the Kempe drill rig. A rented compressor should be used for future work of this nature.

A larger separation than the 3/4 inch used between the invar and normal pendulum wire on this project is recommended to lessen the problems of tangling during installation.

Reading directions should be marked on reading tables to ensure consistency in reporting results. Bullseye survey bubbles are not appropriate to detect accidental movement of reading tables because they moved out of range when the dam tilted naturally under temperature loading. Hand held tiltmeter readings on the wall and table are suggested for this purpose in the future.

A reading schedule of once every month is suggested for the pendulums during the first two years of operation. This should allow identification of the months when minimum and maximum deflections occur due to seasonal temperature fluctuations. A lesser reading frequency, say twice annually, may be adopted after this time, unless unusual deformations are occurring.

Regular data analysis and inspection of these instruments is recommended to ensure they are performing correctly.

7.0 SUMMARY

Two normal pendulums, two inverse pendulums and six survey points were installed at Abitibi Canyon GS main dam. These instruments and their installation was described. Initial readings and suggestions for data interpretation were presented.

ACKNOWLEDGEMENT

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REFERENCES

1. Canadian National Committee of the International Commission on Large Dams, "The Register of Dams in Canada", 1984.

2. Johnson, W.P. "Abitibi Canyon GS - As-Installed Instrumentation - 1983". Geotechnical Engineering Department Report No 84027, January 1984.

3. ICOLD. "Deterioration of Dams and Reservoirs - Examples and Their Analysis". Paris, 1985.

4. Gun[illegible] G. and Morison, W.G. "Measurements of the Structural Behaviour of Concrete Gravity Dams". Research Division Report No 54-533, 1955.

5. Pilot, G. "Instrumentation and Warning Systems for Research and Complex Slope Stability Problems". Fourth International Symposium on Landslides, Vol 1, pp 275-306, Toronto, 1984.

6. Gould, J.P. and Dunnicliff, C.J. "Accuracy of Field Deformation Measurements". Proc 4th Panamerican Conference on Soil Mechanics and Foundation Engineering, Vol 1, pp 313-366 and Vol 111, pp 211-233, San Juan, 1971.

7. Capelle, J.F. "Monitoring the Foundation of a Large Turbine Group with New Non-Contact Instruments". CGS Seminar on Recent Developments in Geotechnical Instrumentation and Monitoring". Toronto, 1984.

8. Meeting with Mr. J. Demers and Mr. R. Hamelin of Hydro Quebec at Beauharnois GS, July 1984.

9. Post, G. "Dams and Foundation Monitoring - General Report", 15th ICOLD, Q.56, Vol I, pp 1623-1727, Lausanne, 1985.

TABLE I

Monitoring Methods that Detected Deterioration of Dams

Method Used	Frequency that Method First Detected Deterioration	
Direct Observation*	951 times	
Water Flow Measurements	158	
Horizontal Displacement Measurement	66	} 130 times
Vertical Displacement Measurement	64	
Sampling and Laboratory Testing	44	
Pore Pressure Measurements	39	
TOTAL NUMBER OF CASES	1105*	

*Direct observation was often used in conjunction with other methods and for many cases it was the only method capable of giving an early warning.

TABLE II

Comparison of Monitoring Systems for Abitibi Canyon GS

System	Accuracy (Inch)	Monitoring Equipment	Monitoring Personnel	Estimated Costs ($'000) Installation	Reading (each set)
Surveying	+/-0.25	complex	survey crew	30	> 10
Inclinometer	+/-0.30/5,6/	complex	instrumentation specialists	40	5
Pendulums	+/-0.005/7,8/	simple	Region staff	50	<< 1
REQUIRED	+/0.02	simple	Region staff		

TABLE III

HORIZONTAL ALIGNMENT SURVEY EQUIPMENT

1 Wilde T2 Theodolite

1 Wilde Z21 Target

1 Wilde Z21 Vernier Target (Adapted)

1 Wilde ZNL16 Optical Plummet (Manual)

1 Topcon Tribrach for T2 (No Optics)

2 Wilde GDf1 Tribrachs (No Optics)

1 Pair Headsets

3 Wilde Wooden Tripods

1 Wilde Aluminum Tripod (Large Connecting Screw for Topcon Tribrach)

VERTICAL PROFILE SURVEY EQUIPMENT

1 Wilde N-3 Metric Level

2 Wilde Invar Levelling Rods (Metric, Multi-tip)

TABLE IV

Initial Readings - Abitibi Canyon GS Pendulums

CHAINAGE 7 + 12 ELEVATION 466

Inverse Pendulum #1

upstream (S)	1.620
downstream (N)	1.441
left (W)	1.549
right (E)	1.526
Invar Wire	1.312

Date: November 27, 1984

Normal Pendulum #2

upstream (S)	1.814
downstream (N)	1.233
left (W)	1.588
right (E)	1.466
Invar Wire	0.126

Date: February 7, 1985

CHAINAGE 8 + 99.5 ELEVATION 450

Inverse Pendulum #1

upstream (S)	1.544
downstream (N)	1.503
left (W)	1.301
right (E)	1.744
Invar Wire	0.821

Date: November 27, 1984

Normal Pendulum #1

upstream (S)	1.559
downstream (N)	1.446
left (W)	1.399
right (E)	1.630
Invar Wire	-

Date: November 27, 1984

TABLE V Abitibi Canyon GS Autocentering Device Initial Readings - Feb/85

PROJET: Abitibi Canyon G.S.

BARRAGE: Inverted Aqueduct #1 B 99.5

DIRECTION PROJETS DE CENTRALES
SERVICE RELEVES TECHNIQUES
DIV. IMPLANTATION & AUSCULTATION

PAGE 1 DE 5

DATE: 85/02/05

TEMP.: 6°C

LECTURE DE PENDULE
LE LONG D'UN TROU
AVEC GUIDE-FIL AUTOCENTREUR

OBSERVATEUR: R. Co...

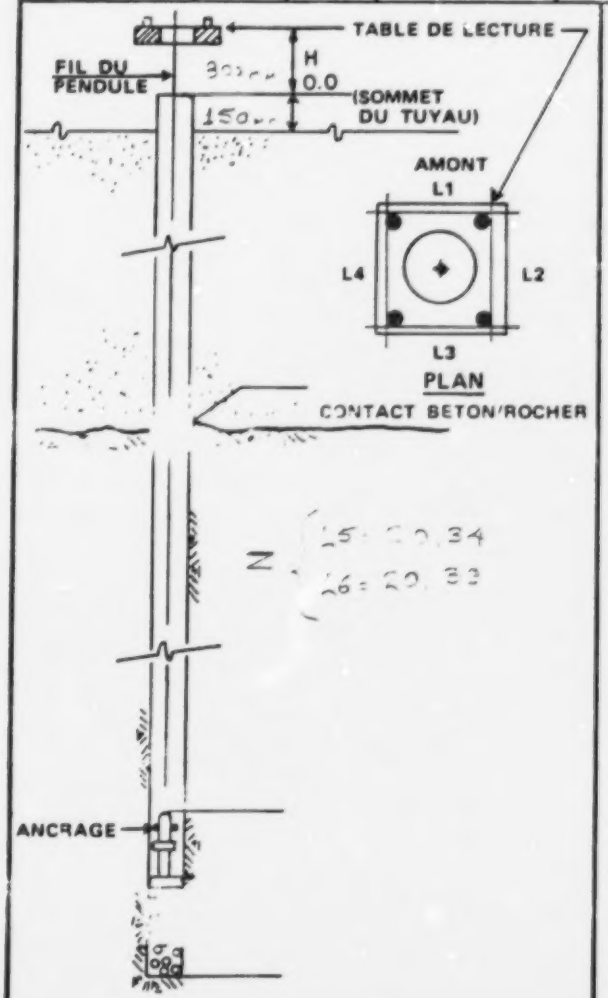
MARQUEUR: J. S...

CALCULE PAR: _____

VERIFIE PAR: _____

PENDULE INVERSE N°: 1 PLOT: IX.

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE Lo	DEPLACEMENT
TABLE DE LECTURE H = 0.200	X	L2	35,52 / 35,50	+ 3,50	(Px) + 3,50		
		L4	42,52 / 42,50				
		L2	35,47	+ 3,50			
		L4	42,43				
HAUTEUR DE LA TABLE AU-DESSUS DU TUYAU)	Y	L1	41,20 / 41,22	- 2,17	(Py) - 2,19		
		L3	36,85 / 36,83				
		L1	41,22	- 2,21			
		L3	36,80				



Z = (25: 20.34
26: 20.33)

METHODE CALCUL:

POUR LA PAGE N° 1,

POSITION DU CENTRE DE LA TABLE DE LECTURE PAR RAPPORT A L'ANCRAGE DU PENDULE:

$X = \frac{L4 - L2}{2}$ $Y = \frac{L3 - L1}{2}$

POUR LES PAGES SUIVANTES,

POSITION DU FIL GUIDE AU CENTRE DU TUYAU A DIFFERENTES PROFONDEURS, PAR RAPPORT A L'ANCRAGE DU PENDULE:

$X = \frac{L2 - L4}{2} + Px$ $Y = \frac{L1 - L3}{2} + Py$

Px = POSITION ACTUELLE DE LA TABLE EN X

Py = POSITION ACTUELLE DE LA TABLE EN Y

DEPLACEMENT AUX DIFFERENTES PROFONDEURS =
POSITION ACTUELLE - POSITION D'ORIGINE

	avec fil	
K = 79,09	79,34	)
K = 78,05	79,32	Y

ALLER

RETOUR

CONSTANTE DE LA TABLE, X: _____
(A L'INSTALLATION) Y: _____

DIAMETRE DU FIL: 127...

DIAMETRE DE L'ADAPTEUR _____ (S'il y a lieu)

DATE: 4 02/05

TEMP.: [illegible]

LECTURE DE PENDULE LE LONG D'UN TROU AVEC GUIDE-FIL AUTOCENTREUR

PAGE 2 DE 5

OBSERVATEUR: R. Co[illegible]

MARQUEUR: J. S[illegible]

CALCULE PAR: _____

VERIFIE PAR: _____

PENDULE INVERSE N° 1 PLOT: 9

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE Lo	DEPLACEMENT
1	X	↓ L2	39,15	-3.66	3,65		
		↓ L4	38,83				
		↑ L2	39,17	3,64			
		↑ L4	38,83				
	Y	↓ L1	37,24	-3,92	-4,01		
		↓ L3	40,71				
		↑ L1	37,22	-4,10			
		↑ L3	40,94				
2	X	↓ L2	41,73	6,18	6,16		
		↓ L4	36,36				
		↑ L2	41,67	6,15			
		↑ L4	36,37				
	Y	↓ L1	42,47	1,29	1,21		
		↓ L3	35,50				
		↑ L1	42,30	1,13			
		↑ L3	35,[illegible]				
3	X	↓ L2	43,53	8,04	7,99		
		↓ L4	34,44				
		↑ L2	43,42	7,95			
		↑ L4	34,54				
	Y	↓ L1	42,40	5,22	5,20		
		↓ L3	31,53				
		↑ L1	42,35	5,19			
		↑ L3	31,[illegible]				
4	X	↓ L2	44,55	9,07	9,07		
		↓ L4	33,40				
		↑ L2	44,58	9,08			
		↑ L4	33,42				
	Y	↓ L1	49,00	7,82	7,76		
		↓ L3	28,98				
		↑ L1	48,89	7,70			
		↑ L3	28,[illegible]				

Px: 3.50

: -2.19

DATE: 85/02/05

TEMP.: 3 -

LECTURE DE PENDULE LE LONG D'UN TROU AVEC GUIDE-FIL AUTOCENTREUR

PAGE 3 DE 5

OBSERVATEUR: RC

MARQUEUR: J.S.

CALCULE PAR: _____

VERIFIE PAR: _____

PENDULE INVERSE N° 1 PLOT: 9

+5°C

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE Lo	DEPLACEMENT
5	X	L2 ↓	44,98	9,49	9,50		
		L4 ↓	33,00				
		L2 ↑	45,00	9,51			
		L4 ↑	32,98				
	Y	L1 ↓	50,84	9,66	9,62		
		L3 ↓	27,13				
		L1 ↑	50,78	9,58			
		L3 ↑	27,24				
6	X	L2 ↓	44,13	8,61	8,59		
		L4 ↓	33,90				
		L2 ↑	44,10	8,58			
		L4 ↑	33,94				
	Y	L1 ↓	51,36	10,15	10,13		
		L3 ↓	26,68				
		L1 ↑	51,33	10,11			
		L3 ↑	26,73				
7	X	L2 ↓	43,31	7,85	7,81		
		L4 ↓	34,61				
		L2 ↑	43,30	7,78			
		L4 ↑	34,74				
	Y	L1 ↓	51,40	10,21	10,16		
		L3 ↓	26,60				
		L1 ↑	51,32	10,12			
		L3 ↑	26,72				
8	X	L2 ↓	42,39	6,88	6,90		
		L4 ↓	35,62				
		L2 ↑	42,42	6,92			
		L4 ↑	35,60				
	Y	L1 ↓	50,27	9,10	9,07		
		L3 ↓	27,68				
		L1 ↑	50,23	9,03			
		L3 ↑	27,72				

Px: 3,50

-2,14

DATE: 85 05 05

TEMP.:

LECTURE DE PENDULE LE LONG D'UN TROU AVEC GUIDE-FIL AUTOCENTREUR

.. 4 ..

OBSERVATEUR: R. C...

MARQUEUR: J. S...

CALCULE PAR:

VERIFIE PAR:

PENDULE INVERSE N° 1 PLOT: 9

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE Lo	DEPLACEMENT
9	X	L2	41,85	6,34	6,33		
		L4	36,16				
		L2	42,86	6,33			
		L4	36,20				
	Y	L1	49,79	8,60	8,53		
		L3	28,20				
		L1	42,67	8,47			
		L3	28,25				
10	X	L2	40,85	5,32	5,30		
		L4	37,21				
		L2	42,20	5,28			
		L4	37,23				
	Y	L1	48,22	7,04	7,01		
		L3	29,76				
		L1	43,28	6,99			
		L3	29,29				
11	X	L2	39,46	3,94	3,90		
		L4	38,57				
		L2	39,34	3,87			
		L4	38,60				
	Y	L1	46,92	5,70	5,66		
		L3	31,13				
		L1	43,79	5,63			
		L3	31,15				
12	X	L2	38,82	3,34	3,33		
		L4	39,14				
		L2	38,37	3,33			
		L4	38,20				
	Y	L1	44,57	3,41	3,37		
		L3	33,36				
		L1	44,50	3,33			
		L3	39,46				

Px: 3,50

-2,19

DATE: 85/02/05

TEMP.: _____

LECTURE DE PENDULE LE LONG D'UN TROU AVEC GUIDE-FIL AUTOCENTREUR

OBSERVATEUR: [illegible]

MARQUEUR: [illegible]

CALCULE PAR: _____

VERIFIE PAR: _____

PENDULE INVERSE N° 1 PLOT: 9

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE Lo	DEPLACEMENT
13	X	L2	37,95	2,48	2,45		
		L4	40,00				
		L2	37,90	2,42			
		L4	40,32				
	Y	L1	42,97	1,76	1,76		
		L3	35,06				
		L1	42,34	1,76			
		L3	35,02				
Px: 3,50 -2,12	X	L2					
		L4					
		L2					
		L4					
	Y	L1					
		L3					
		L1					
		L3					
	X	L2					
		L4					
		L2					
		L4					
	Y	L1					
		L3					
		L1					
		L3					
	X	L2					
		L4					
		L2					
		L4					
	Y	L1					
		L3					
		L1					
		L3					

POND. No. 1

PROF. 13

L2 37.96	2.48	
L4 40.00		2.45
L2 37.98	2.42	
L4 40.06		
L1 42.97	1.76	
L3 35.06		1.76
L1 42.94	1.76	
L3 35.04		

PROF. 12

L2 38.82	3.34	
L4 33.14		3.33
L2 38.87	3.33	
L4 39.28		
L1 44.57	3.41	
L3 33.36		3.37
L1 44.58	3.33	
L3 33.46		

PROF. 11

L2 39.46	3.94	
L4 38.57		3.98
L2 38.34	3.87	
L4 38.68		
L1 46.92	5.78	
L3 31.13		5.66
L1 46.73	5.63	
L3 31.15		

PROF. 10

L2 40.85	5.32	
L4 37.21		5.28
L2 40.88	5.28	
L4 37.23		
L1 48.22	7.84	
L3 29.26		7.81
L1 48.18	6.99	
L3 29.91		

PROF. 9

L2 41.85	6.74	
L4 36.16		6.73
L2 41.86	6.33	
L4 36.28		
L1 45.79	8.68	
L3 28.28		8.53
L1 45.62	8.42	
L3 28.35		

PROF. 8

L2 42.39	6.88	
L4 35.62		6.98
L2 42.44	6.92	
L4 35.68		
L1 50.27	9.18	
L3 27.68		9.87
L1 50.23	9.83	
L3 27.78		

PROF. 7

L2 43.31	7.85	
L4 34.61		7.81
L2 43.38	7.78	
L4 34.74		
L1 51.48	10.21	
L3 26.68		10.16
L1 51.31	10.12	
L3 26.68		

PROF. 6

L2 44.13	8.61	
L4 33.98		8.59
L2 44.19	8.58	
L4 33.94		
L1 51.36	10.15	
L3 26.68		10.13
L1 51.33	10.11	
L3 26.73		

PROF. 5

L2 44.98	9.49	
L4 33.88		9.58
L2 45.08	9.51	
L4 32.98		
L1 50.84	9.66	
L3 27.13		9.62
L1 50.79	9.58	
L3 27.24		

PROF. 4

L2 44.55	9.87	
L4 33.49		9.87
L2 44.58	9.88	
L4 33.42		
L1 49.88	7.82	
L3 28.98		7.76
L1 49.85	7.78	
L3 29.11		

PROF. 3

L2 43.53	8.84	
L4 34.44		7.93
L2 43.44	7.95	
L4 34.54		
L1 46.48	5.22	
L3 31.58		5.28
L1 46.35	5.18	
L3 31.58		

PROF. 2

L2 41.73	6.18	
L4 36.36		6.16
L2 41.62	6.15	
L4 36.37		
L1 42.47	1.25	
L3 35.59		1.21
L1 42.38	1.13	
L3 35.65		

PROF. 1

L2 38.15	3.66	
L4 38.83		3.65
L2 38.17	3.64	
L4 38.88		
L1 37.24	-3.92	
L3 43.21		4.01
L1 37.12	-4.19	
L3 43.34		

PROJET: ABITIBI Canyon

BARRAGE: Inverted Pendulum #2 Tour

DIRECTION PROJETS DE CENTRALES
SERVICE RELEVES TECHNIQUES
DIV. IMPLANTATION & AUSCULTATION

PAGE 1 DE

DATE: 85/02/06

TEMP.:

LECTURE DE PENDULE
LE LONG D'UN TROU
AVEC GUIDE-FIL AUTOCENTREUR

OBSERVATEUR: J. S.

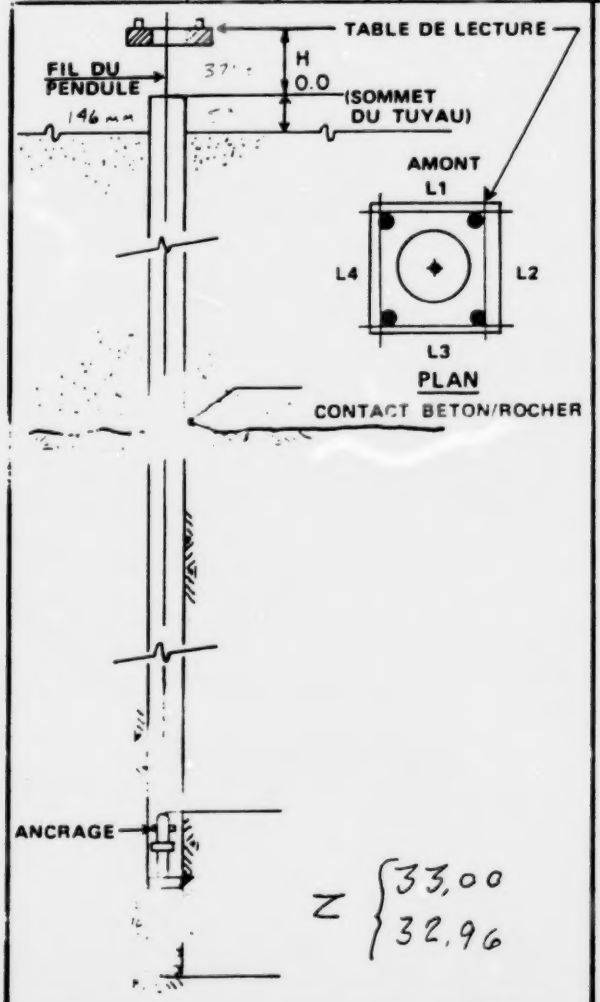
MARQUEUR: R C

CALCULE PAR:

VERIFIE PAR:

PENDULE INVERSE N°: 2 PLOT:

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE Lo	DEPLACEMENT
TABLE DE LECTURE H = 352 mm	X	L2 ↓	39.32 / 39,40 / 36	- 0,36	(Px) - 0,41		
		L4 ↓	38,64 / 38,64 / 64				
		L2 ↑	39,42	- 0,46			
		L4 ↑	38,50				
HAUTEUR DE LA TABLE AU-DESSUS DU TUYAU)	Y	L1 ↓	41,56 / 41,55 / 55	- 2,55	(Py) - 2,62		
		L3 ↓	36,48 / 36,46				
		L1 ↑	41,71	- 2,70			
		L3 ↑	36,30				



METHODE CALCUL:

POUR LA PAGE N° 1,

POSITION DU CENTRE DE LA TABLE DE LECTURE PAR RAPPORT A L'ANCRAGE DU PENDULE:

$X = \frac{L4 - L2}{2}$ $Y = \frac{L3 - L1}{2}$

POUR LES PAGES SUIVANTES,

POSITION DU FIL GUIDE AU CENTRE DU TUYAU A DIFFERENTES PROFONDEURS, PAR RAPPORT A L'ANCRAGE DU PENDULE:

$X = \frac{L2 - L4}{2} + Px$ $Y = \frac{L1 - L3}{2} + Py$

Px = POSITION ACTUELLE DE LA TABLE EN X

Py = POSITION ACTUELLE DE LA TABLE EN Y

DEPLACEMENT AUX DIFFERENTES PROFONDEURS =
POSITION ACTUELLE – POSITION D'ORIGINE

↓ ALLER

↑ RETOUR

CONSTANTE DE LA TABLE, X: 79,37
(A L'INSTALLATION) Y: 79,35

78,09 A/C F/C

DIAMETRE DU FIL: 1,27

DIAMETRE DE L'ADAPTEUR _____ (S'il y a lieu)

DATE: 85/02/06

TEMP.: _____

LECTURE DE PENDULE LE LONG D'UN TROU AVEC GUIDE-FIL AUTOCENTREUR

PAGE 2 DE 5

OBSERVATEUR: J. Seguin

MARQUEUR: R. Côté

CALCULE PAR: _____

VERIFIE PAR: _____

PENDULE INVERSE N° 2 PLOT: _____

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE La	DEPLACEMENT
1	X	L2 ↓	20,80	-3,57	-[illegible]		
		L4 ↓	57,12				
		L2 ↑	20,98	[illegible]			
		L4 ↑	56,94				
	Y	L1 ↓	38,78	-2,86	-2,74		
		L3 ↓	39,26				
		L1 ↑	39,00	-2,63			
		L3 ↑	39,03				
2	X	L2 ↓	18,66	-2,79	-2,93		
		L4 ↓	59,42				
		L2 ↑	18,88	-2,57			
		L4 ↑	59,20				
	Y	L1 ↓	39,87	[illegible]	[illegible]		
		L3 ↓	38,18				
		L1 ↑	40,07	[illegible]			
		L3 ↑	37,94				
3	X	L2 ↓	16,77	[illegible]	[illegible]		
		L4 ↓	61,25				
		L2 ↑	16,85	[illegible]			
		L4 ↑	61,04				
	Y	L1 ↓	40,29	[illegible]	[illegible]		
		L3 ↓	37,75				
		L1 ↑	40,47	[illegible]			
		L3 ↑	37,53				
4	X	L2 ↓	16,04	[illegible]	[illegible]		
		L4 ↓	62,02				
		L2 ↑	16,15	[illegible]			
		L4 ↑	61,85				
	Y	L1 ↓	41,05	[illegible]	[illegible]		
		L3 ↓	36,96				
		L1 ↑	41,19	[illegible]			
		L3 ↑	36,82				

Px: _____

_____

DATE: 85/02/06

TEMP.: 6°C

HYDRO QUÉBEC
LECTURE DE PENDULE
LE LONG D'UN TROU
AVEC GUIDE-FIL AUTOCENTREUR

...3...5

OBSERVATEUR: J. Séguin

MARQUEUR: RCOTE

CALCULE PAR: _____

VERIFIE PAR: _____

PENDULE INVERSE N° 2 PLOT: _____

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE Lo	DEPLACEMENT
5	X	L2	15,31	-24,11	-24,02		
		L4	62,72				
		L2	15,46	-23,94			
		L4	62,52				
	Y	L1	41,52	-0,11	0,00		
		L3	36,51				
		L1	41,75	-0,13			
		L3	36,25				
6	X	L2	16,05	-23,36	-23,30		
		L4	61,96				
		L2	16,15	-23,23			
		L4	61,80				
	Y	L1	42,14	0,47	0,53		
		L3	35,95				
		L1	42,24	0,60			
		L3	35,80				
7	X	L2	18,42	-22,00	-22,07		
		L4	59,60				
		L2	18,53	-22,14			
		L4	59,40				
	Y	L1	41,60	-0,03	-0,02		
		L3	36,42				
		L1	41,75	-0,09			
		L3	36,35				
8	X	L2	20,66	-18,76	-18,73		
		L4	57,36				
		L2	20,64	-18,71			
		L4	57,25				
	Y	L1	41,45	-0,16	-0,14		
		L3	36,58				
		L1	41,65	-0,12			
		L3	36,37				

Px: _____

DP22 suite (05-12-77)

86-63

DATE: 85/02/06

TEMP.: 6°C

LECTURE DE PENDULE LE LONG D'UN TROU AVEC GUIDE-FIL AUTOCENTREUR

--- 4 --- 5

OBSERVATEUR: J. Séguin

MARQUEUR: R. Côté

CALCULE PAR: _____

VERIFIE PAR: _____

PENDULE INVERSE N° 2 PLOT: _____

Px: _____

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE Lo	DEPLACEMENT
9	X	L2 ↓	23,22	-16,20	-16,14		
		L4 ↓	54,80				
		L2 ↑	23,28	-16,08			
		L4 ↑	54,65				
	Y	L1 ↓	41,75	0,14	0,22		
		L3 ↓	36,22				
		L1 ↑	41,94	0,30			
		L3 ↑	36,11				
10	X	L2 ↓	27,07	-12,34	-12,30		
		L4 ↓	50,94				
		L2 ↑	27,12	-12,26			
		L4 ↑	50,82				
	Y	L1 ↓	42,40	0,23	0,17		
		L3 ↓	35,57				
		L1 ↑	42,57	0,15			
		L3 ↑	35,43				
11	X	L2 ↓	30,80	-3,53	-3,54		
		L4 ↓	47,15				
		L2 ↑	30,87	-3,51			
		L4 ↑	47,05				
	Y	L1 ↓	42,47	0,22	0,23		
		L3 ↓	35,55				
		L1 ↑	42,60	0,24			
		L3 ↑	35,47				
12	X	L2 ↓	34,62	-4,38	-4,36		
		L4 ↓	43,40				
		L2 ↑	34,65	-4,33			
		L4 ↑	43,30				
	Y	L1 ↓	42,00	0,13	0,17		
		L3 ↓	35,97				
		L1 ↑	42,13	0,21			
		L3 ↑	35,85				

DATE: 85/02/06

TEMP.: 6°C

LECTURE DE PENDULE LE LONG D'UN TROU AVEC GUIDE-FIL AUTOCENTREUR

.. 5 ..

OBSERVATEUR: J.S

MARQUEUR: R.C

CALCULE PAR: _____

VERIFIE PAR: _____

PENDULE INVERSE N° 2 PLOT: _____

PROFONDEUR m	AXE	LECT. N°	LECTURE mm	POSITION	POSITION MOYENNE ACTUELLE	POSITION D'ORIGINE Lo	DEPLACEMENT
13	X	L2 ↓	37,45	-1,33	-1,32		
		L4 ↓	40,60				
		L2 ↑	37,51	-1,86			
		L4 ↑	40,42				
	Y	L1 ↓	41,77	0,12	0,12		
		L3 ↓	36,30				
		L1 ↑	41,75	0,13			
		L3 ↑	36,25				
	X	L2 ↓					
		L4 ↓					
		L2 ↑					
		L4 ↑					
	Y	L1 ↓					
		L3 ↓					
		L1 ↑					
		L3 ↑					
	X	L2 ↓					
		L4 ↓					
		L2 ↑					
		L4 ↑					
	Y	L1 ↓					
		L3 ↓					
		L1 ↑					
		L3 ↑					
	X	L2 ↓					
		L4 ↓					
		L2 ↑					
		L4 ↑					
	Y	L1 ↓					
		L3 ↓					
		L1 ↑					
		L3 ↑					

Px: _____

_____

PROF. 1

	X	
L2	20.80	
		-18.57
L4	57.12	
		-18.48
L2	20.98	
		-18.39
L4	56.94	

	Y	
L1	38.78	
		-2.86
L3	39.26	
		-2.74
L1	39.00	
		-2.63
L3	39.03	

PROF. 2

	X	
L2	18.66	
		-20.79
L4	59.42	
		-20.68
L2	18.88	
		-20.57
L4	59.20	

	Y	
L1	39.87	
		-1.77
L3	38.18	
		-1.66
L1	40.07	
		-1.55
L3	37.94	

PROF. 3

	X	
L2	16.77	
		-22.65
L4	61.25	
		-22.57
L2	16.85	
		-22.50
L4	61.04	

	Y	
L1	40.29	
		-1.35
L3	37.75	
		-1.25
L1	40.47	
		-1.15
L3	37.53	

PROF. 4

	X	
L2	16.04	
		-23.40
L4	62.02	
		-23.33
L2	16.15	
		-23.26
L4	61.85	

	Y	
L1	41.05	
		-0.57
L3	36.96	
		-0.50
L1	41.19	
		-0.43
L3	36.82	

PROF. 5

	X	
L2	15.31	
		-24.11
L4	62.72	
		-24.02
L2	15.46	
		-23.94
L4	62.52	

	Y	
L1	41.52	
		-0.11
L3	36.51	
		0.00
L1	41.75	
		0.13
L3	36.25	

PROF. 6

	X	
L2	16.05	
		-23.36
L4	61.96	
		-23.30
L2	16.15	
		-23.23
L4	61.80	

	Y	
L1	42.14	
		0.47
L3	35.93	
		0.53
L1	42.24	
		0.60
L3	35.80	

PROF. 7

X

L2 18.42
-21.00
L4 59.60
-20.92
L2 18.53
-20.84
L4 59.40

Y

L1 41.60
-0.03
L3 36.42
0.02
L1 41.75
0.08
L3 36.35

PROF. 8

X

L2 20.66
-18.76
L4 57.36
-18.73
L2 20.64
-18.71
L4 57.25

Y

L1 41.45
-0.18
L3 36.58
-0.08
L1 41.65
0.02
L3 36.37

PROF. 9

X

L2 23.22
-16.20
L4 54.80
-16.14
L2 23.28
-16.09
L4 54.65

Y

L1 41.75
0.14
L3 36.22
0.22
L1 41.34
0.29
L3 36.11

PROF. 10

X

L2 27.07
-12.34
L4 50.94
-12.30
L2 27.12
-12.26
L4 50.82

Y

L1 42.40
0.79
L3 35.57
0.87
L1 42.57
0.95
L3 35.43

PROF. 11

X

L2 30.80
-8.58
L4 47.15
-8.54
L2 30.87
-8.50
L4 47.05

Y

L1 42.47
0.84
L3 35.55
0.89
L1 42.60
0.94
L3 35.47

PROF. 12

X

L2 34.62
-4.80
L4 43.40
-4.76
L2 34.65
-4.73
L4 43.30

Y

L1 42.00
0.39
L3 35.97
0.47
L1 42.18
0.54
L3 35.85

PROF. 13

X

L2 37.45
-1.98
L4 40.60
-1.92
L2 37.51
-1.86
L4 40.42

Y

L1 41.77
0.11
L3 36.30
0.12
L1 41.75
0.13
L3 36.25

TABLE VI

Abitibi Canyon GS Deck Survey
Initial Elevations

Station	ELEVATION (cm)	ELEVATION (ft)
1	0*	0*
2	- 5.670	-0.019
3	-13.675	-0.045
4	-33.545	-0.110
5	124.335	0.408
6	105.600	0.346
7	124.870	0.410
8	- 7.765	-0.025

*reference

NOTE: see Figure 2 for locations at survey stations

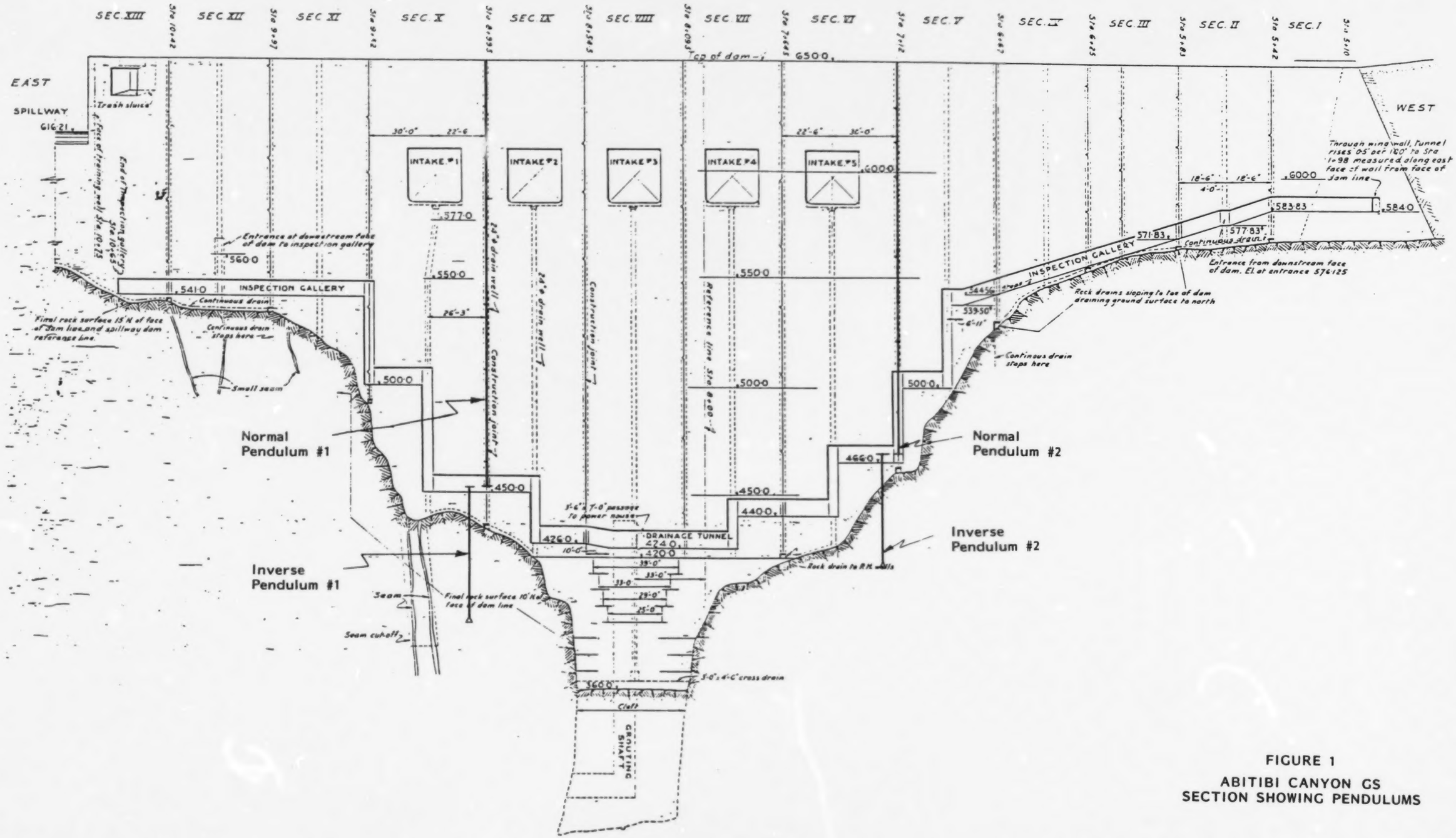
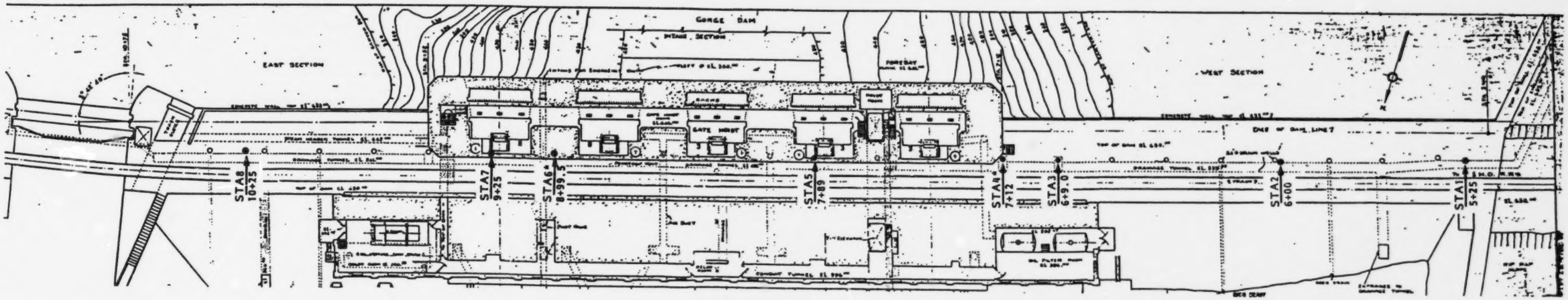


FIGURE 1

ABITIBI CANYON GS
SECTION SHOWING PENDULUMS

200669-RD

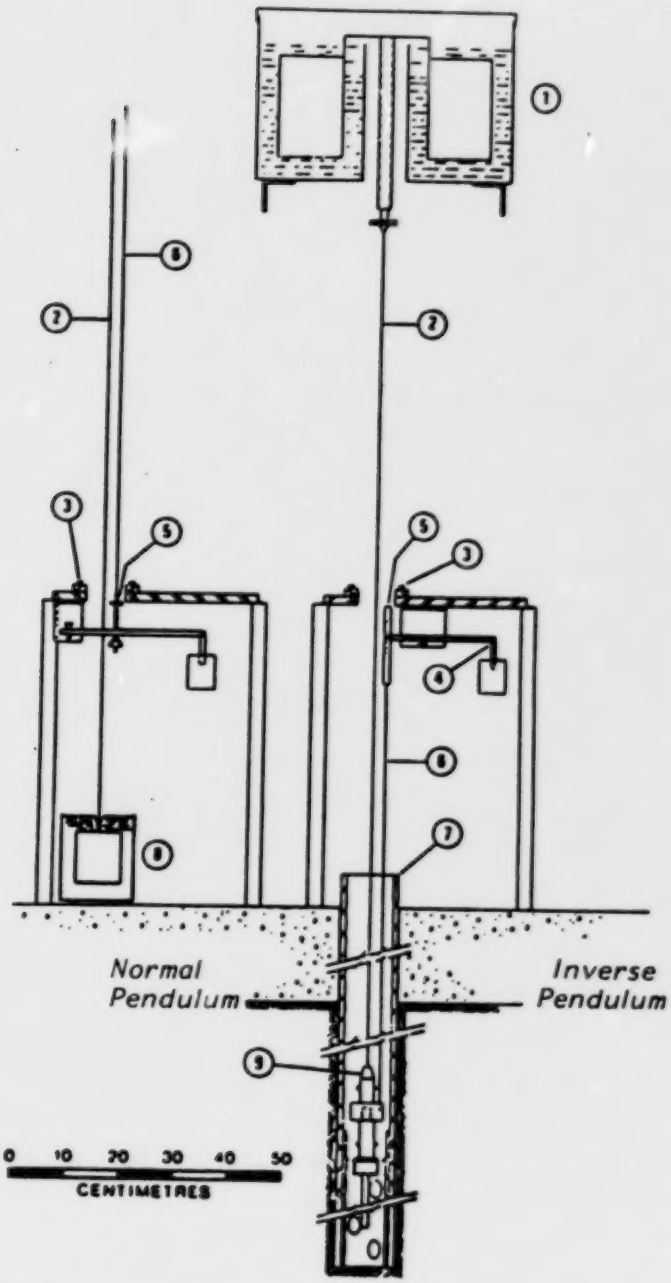


*NORMAL PENDULUM
(IN CONSTRUCTION
JOINT DRAIN)

FIGURE 2

ABITIBI CANYON GS PLAN OF
SURVEY STATION AND
NORMAL PENDULUM LOCATIONS

200668-RD



Legend: *Pendulum Parts*

1. *Tank and float (19kg)*
2. *Pendulum wire*
3. *Reading Table*
4. *Counterweight tension device*
5. *Bench Mark*
6. *Leveling wire (INVAR)*
7. *Casing (60mm de diam.)*
8. *Tank and Weight (11kg)*
9. *Removable anchor-head*

FIGURE 3

SCHEMATIC OF PENDULUMS

171937 RD

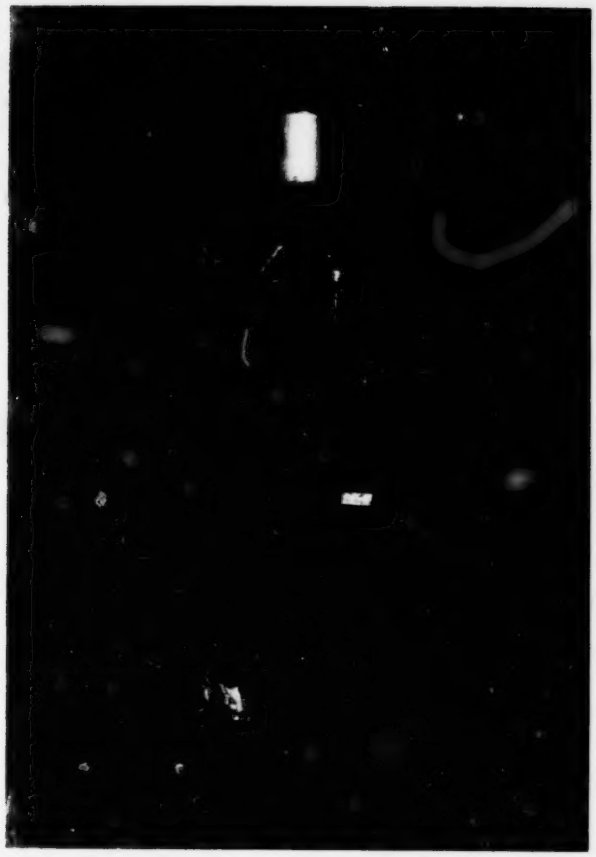


FIGURE 4
KEMPE DRILL

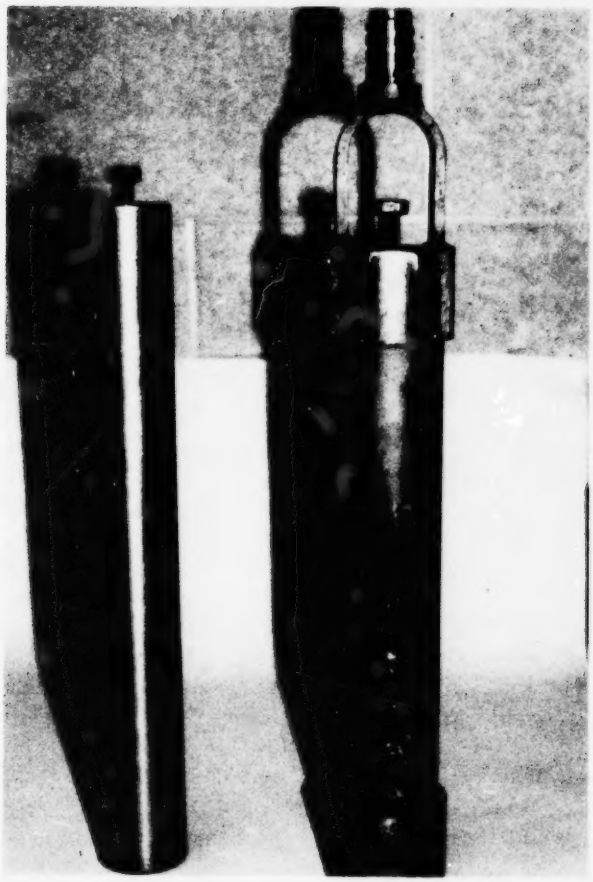


FIGURE 5
WEIGHT TO PLACE INSIDE NQ RODS
(LEFT) OR INSIDE NQ HOLE (RIGHT)

FIGURE 6

CENTERING FLOAT (SUPPORTS WEIGHT)
OVER NQ DRILL RODS IN HOLE

FIGURE 7

MEASURING PLUMB OF
NQ DRILL HOLE

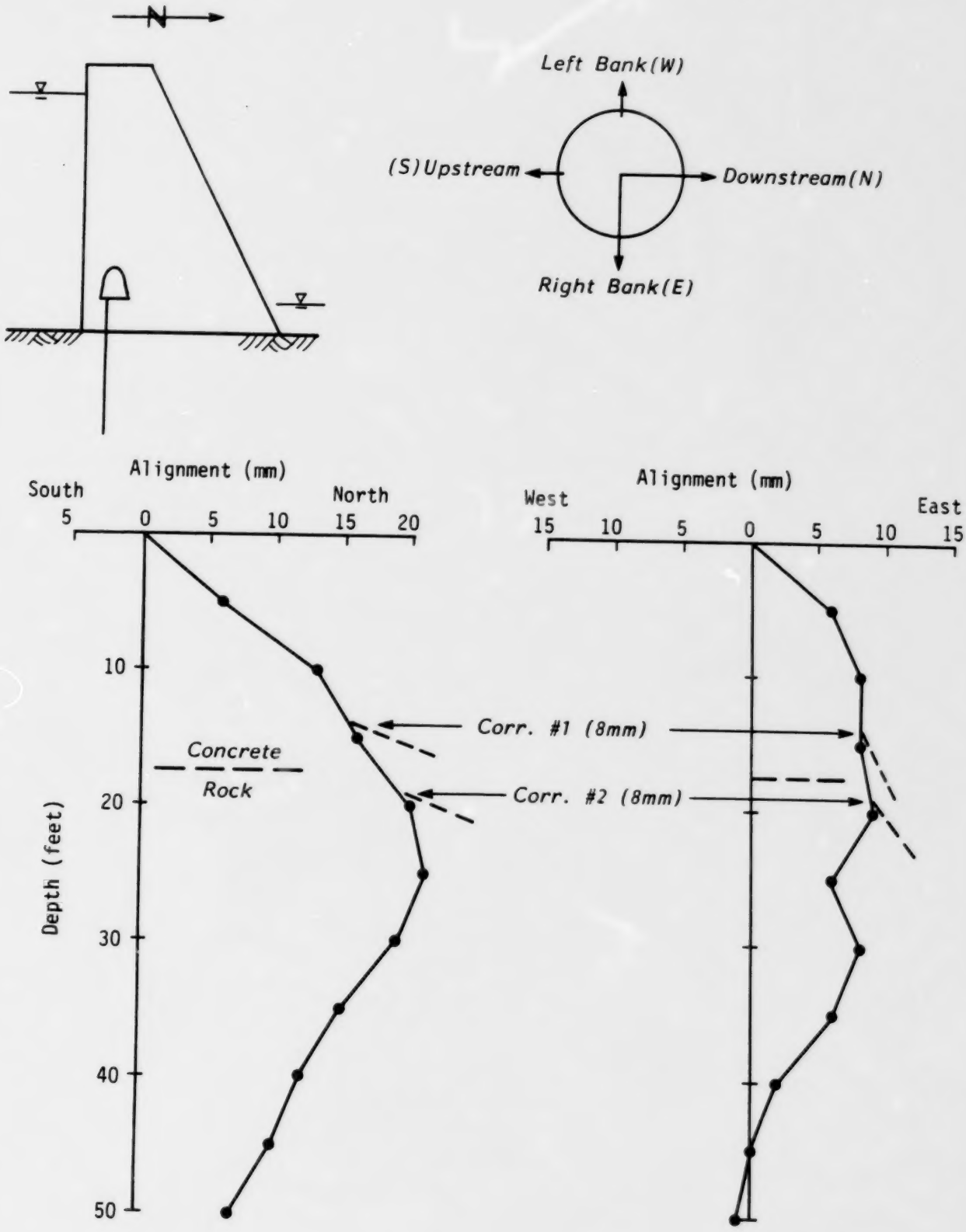


FIGURE 8

PLUMB MEASUREMENTS ON INVERSE PENDULUM 1 AT 8+99.5 DURING DRILLING

171940 RD

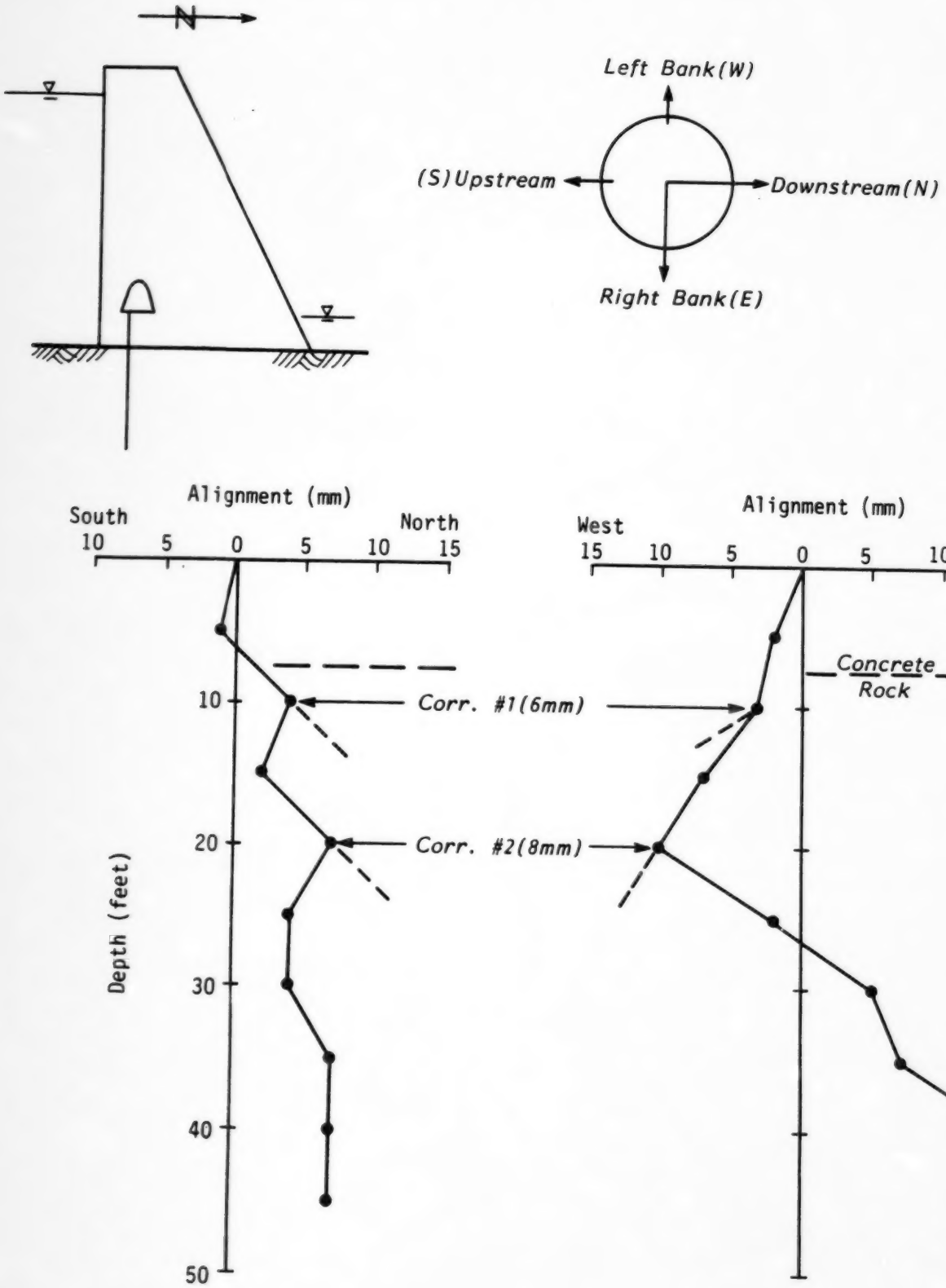


FIGURE 9

PLUMB MEASUREMENTS ON INVERSE PENDULUM 2
AT 7+12 DURING DRILLING

171941 RD

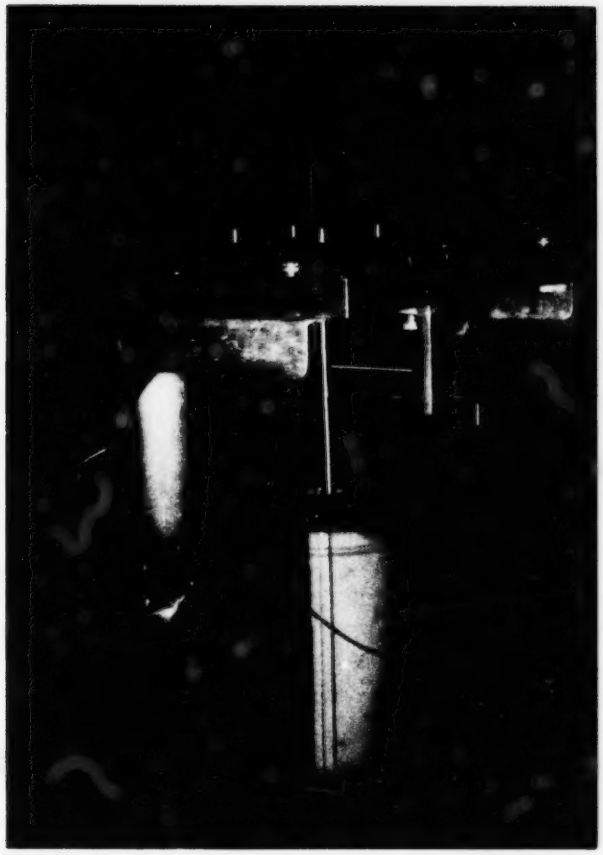


FIGURE 10
COMPLETED INVERSE PENDULUM

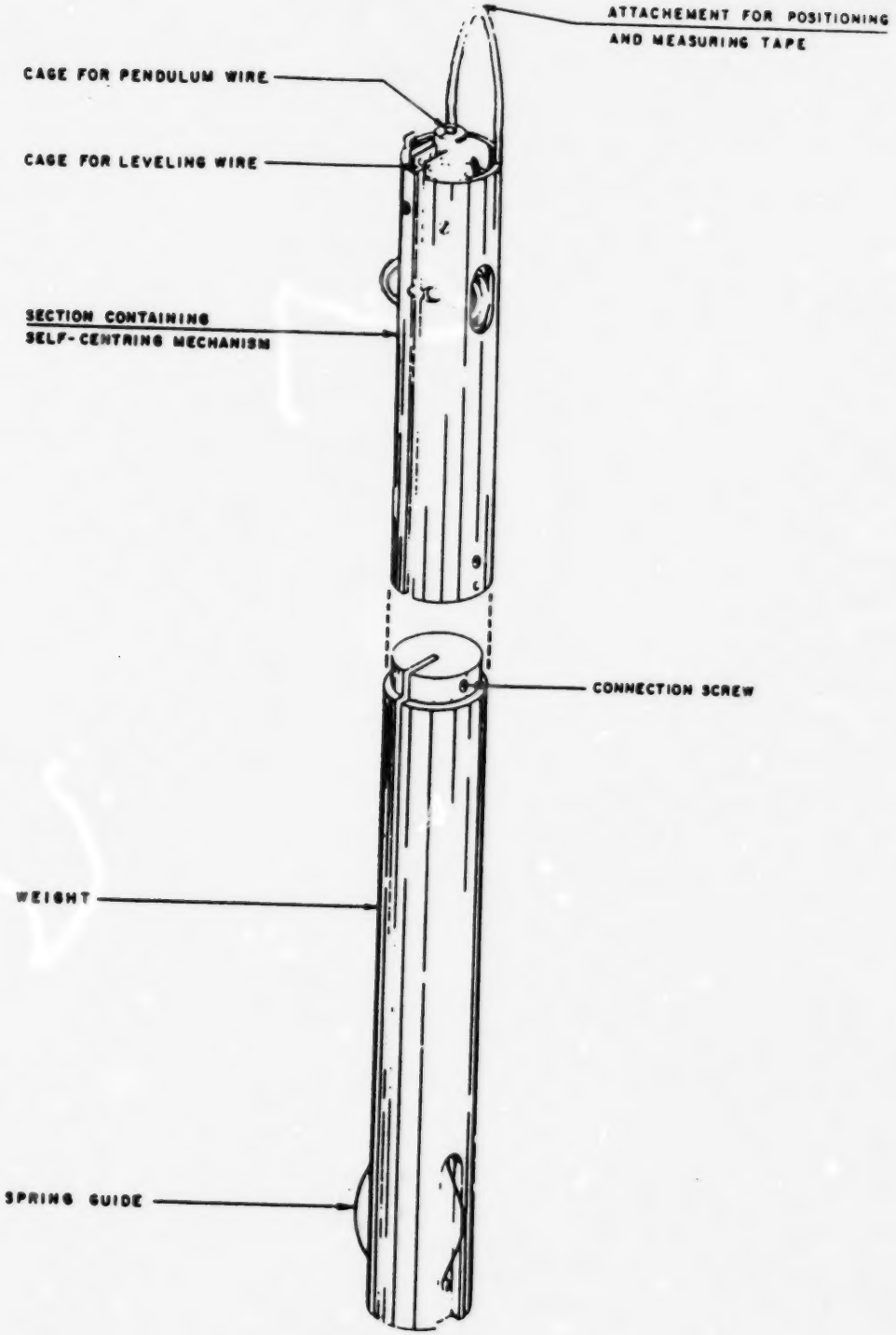


FIGURE 11
PENDULUM WIRE AUTO-CENTRING DEVICE

APPENDIX A

METHOD OF TAKING MEASUREMENTS ON INVERSE AND NORMAL PENDULUMS

INTRODUCTION

Normal and inverse pendulums permit horizontal and vertical movements within the dam to be measured. This appendix describes the methods to be used in making these horizontal and vertical movement measurements.

HORIZONTAL READINGS

A) Method

As the pendulum wire is always vertical, pendulums measure relative horizontal deformations occurring in the structure between their anchorage points and their reading tables (see Figure A1). The deformation measured is the distance from the vertical posts on the reading table to the pendulum wire (see Figure A2). This distance is normally measured with a digital depth micrometer. The face of the micrometer is held tightly against the reading table posts and the tip is advanced until it just touches the pendulum wire (see Figure A3). To produce good readings, the micrometer must touch the wire but must not move it. Care, patience and a good light are essential. If the wire is moved unintentionally, wait until all visible movement has stopped before taking the next readings.

B) Number of Readings

Each reading table should be read from all four sides. Each side should be read at least three times or until three readings are obtained that agree within +/- 0.004 inch. These repeat readings for one side are best done by retracting and readvancing the micrometer tip without taking the micrometer off the reading table posts. This procedure usually requires a two man team, with the second man holding the light and recording the readings.

C) Recording the Readings

Readings are recorded on a separate sheet for each pendulum chainage. Occasionally, both the inverted and normal pendulum readings at one chainage will go on the same sheet. The compass directions are marked on each reading table. These directions may differ from the conventional used at some plants. Care is required to ensure the readings are recorded in the right place.

After recording all the readings for a pendulum, the readings for each direction should be averaged. As a check, the sum of the north plus south readings and the sum of the east plus west readings should be compared to the table constant on the reading sheet. (The table constant is the distance between the posts minus the thickness of the pendulum wire.) These numbers should match within +/- 0.010 inch. If they do not match this closely, the readings should be repeated.

Once acceptable readings are obtained, the average readings should be copied onto the appropriate summary sheet for the pendulum. Any large change in readings from the previous readings should be confirmed by checking that the pendulum equipment is not damaged and the readings are properly recorded. Copies of the reading sheets and summary sheets should be

forwarded to the Civil Works Department, Dam Safety Group. Originals should be kept on file at the local record centre. Examples of the reading and summary sheets are attached.

VERTICAL READINGS

A) Method

To take vertical movement measurements, use the same digital depth micrometer used for the horizontal measurements. Place the micrometer vertically over the centre hole of the reading table (see Figure A4) and measure down to the pin attached to the invar wire for inverse pendulums (see Figure A5) or to the block attached to the invar wire for normal pendulums (see Figure A6). The invar wire passes through the reading table for normal pendulums only.

B) Number of Readings

Take three readings, as for the pendulum wire, and take additional readings if the initial three do not agree within +/- 0.004 inch.

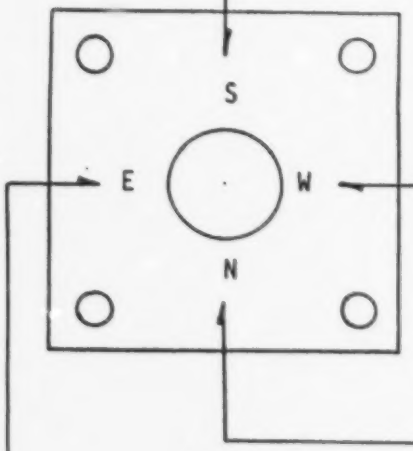
C) Recording the Readings

Use the same reading and summary sheets for vertical readings as were used for the horizontal readings.

ABITIBI CANYON GS
ABITIBI 1 PENDULUMS
450 ELEV, 8+99.5

DATE:

Inverted Pendulum



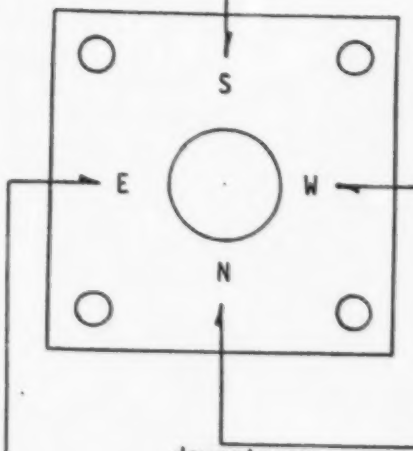
original reading
current reading 1
2
3
Average

original reading
current reading 1
2
3
Average

original reading
current reading 1
2
3
Average

original reading
current reading 1
2
3
Average

Normal Pendulum



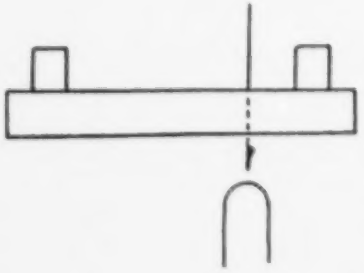
original reading
current reading 1
2
3
Average

original reading
current reading 1
2
3
Average

original reading
current reading 1
2
3
Average

original reading
current reading 1
2
3
Average

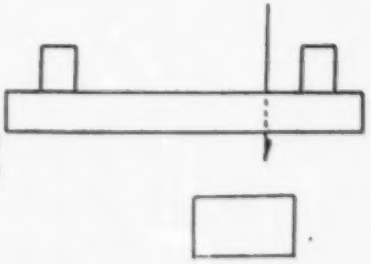
Invar/Pin



original reading
current reading 1
2
3
Average

READING CHECK
- sum of N & S should = 3.060
- sum of E & W should = 3.060

Invar/Block



original reading
current reading 1
2
3
Average

ABITIBI CANYON GS
ABITIBI 1 PENDULUMS
450 ELEVATION, 8+99.5

Inverted Pendulum

DIRECTION	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG
NORTH											
SOUTH											
EAST											
WEST											

INVAR WIRE (PIN)

DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG

ABITIBI CANYON GS
ABITIBI 1 PENDULUMS
450 ELEVATION, 8+99.5

Normal Pendulum

DIRECTION	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG
NORTH											
SOUTH											
EAST											
WEST											

INVAR WIRE (Block)

DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG	DATE RDG

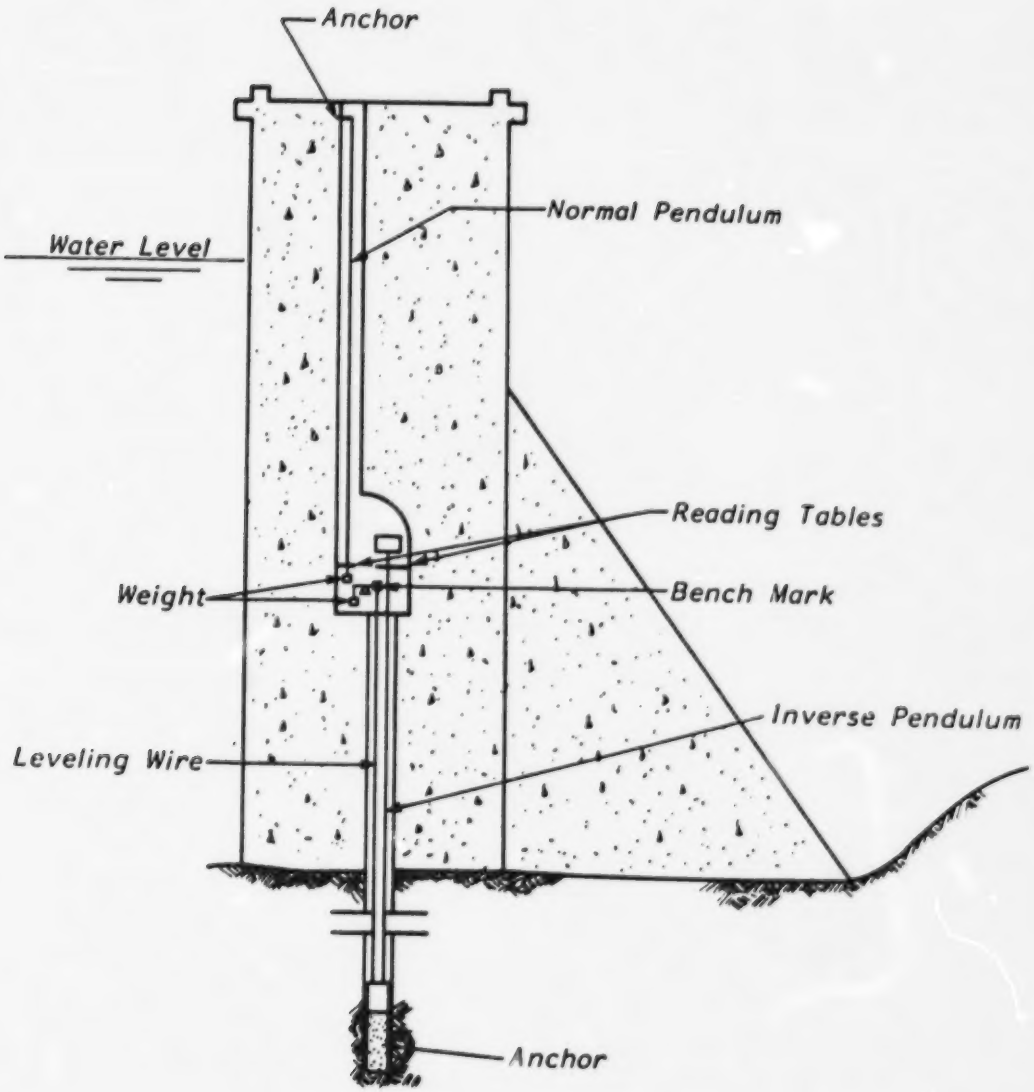


FIGURE A1
TYPICAL SECTION (NORMAL & INVERSE PENDULUM)

172876-RD

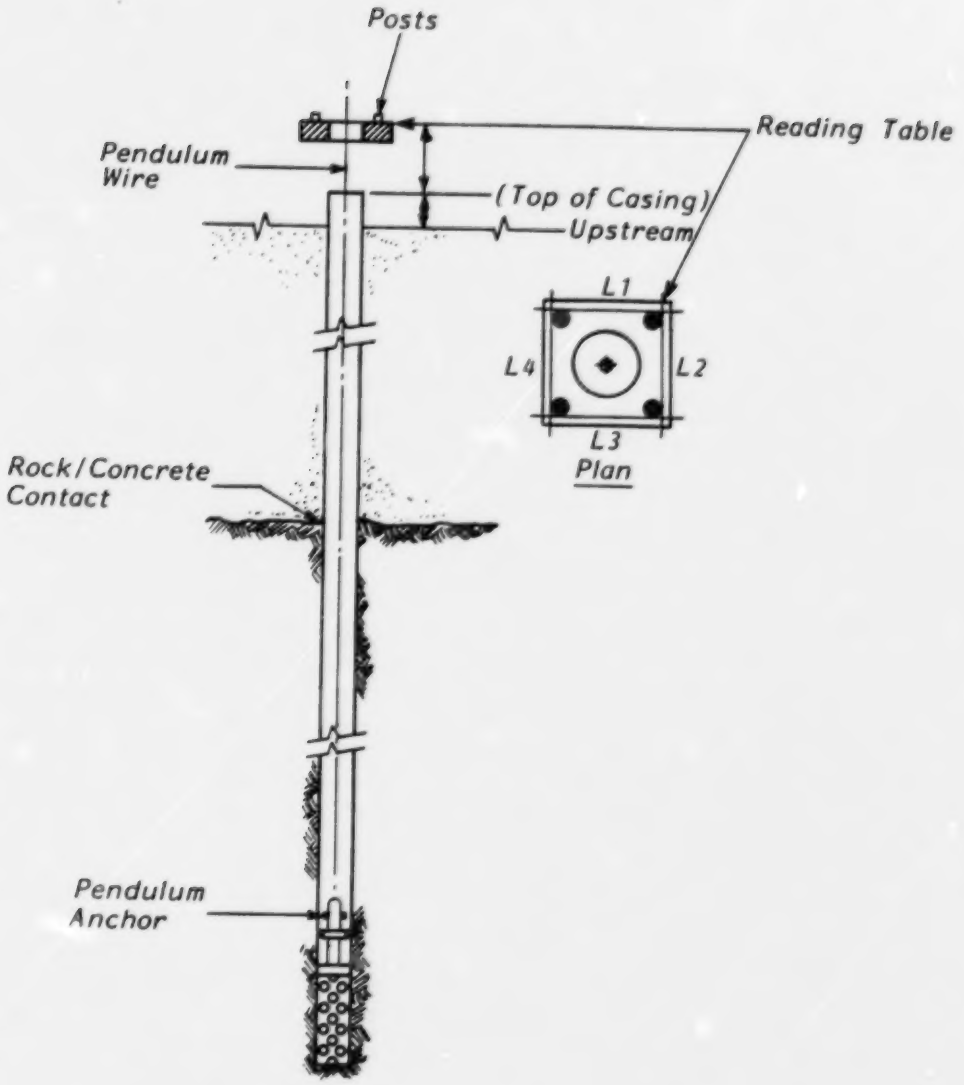

Posts
Reading Table
Pendulum Wire
(Top of Casing)
Upstream
L1
L4
L2
L3
Plan
Rock/Concrete Contact
Pendulum Anchor

FIGURE A2

FIGURE A3

POSITION OF MICROMETER
FOR READING PENDULUM WIRE

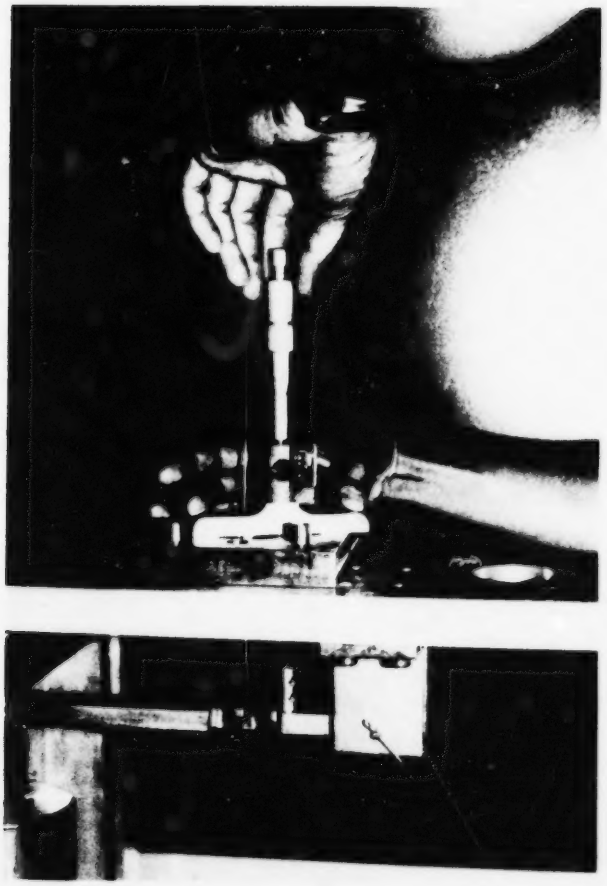
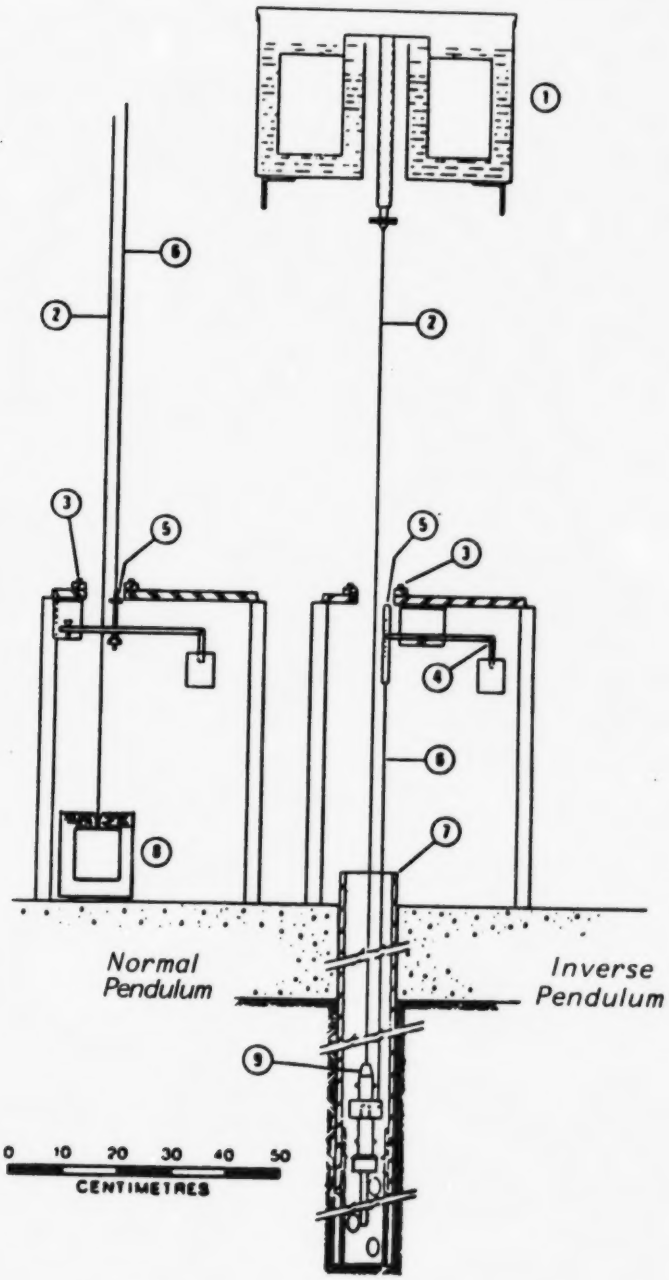


FIGURE A4

POSITION OF MICROMETER
FOR READING INVAR (LEVELLING)
WIRE ON NORMAL
PENDULUM ASSEMBLY



Legend: Pendulum Parts

1. Tank and float (19kg)
2. Pendulum wire
3. Reading Table
4. Counterweight tension device
5. Bench Mark
6. Leveling wire (INVAR)
7. Casing (60mm de diam.)
8. Tank and Weight (11kg)
9. Removable anchor-heaa

FIGURE A5

SCHEMATIC OF PENDULUMS

172875-RD

APPENDIX B

INTERPRETATION OF PENDULUM READINGS

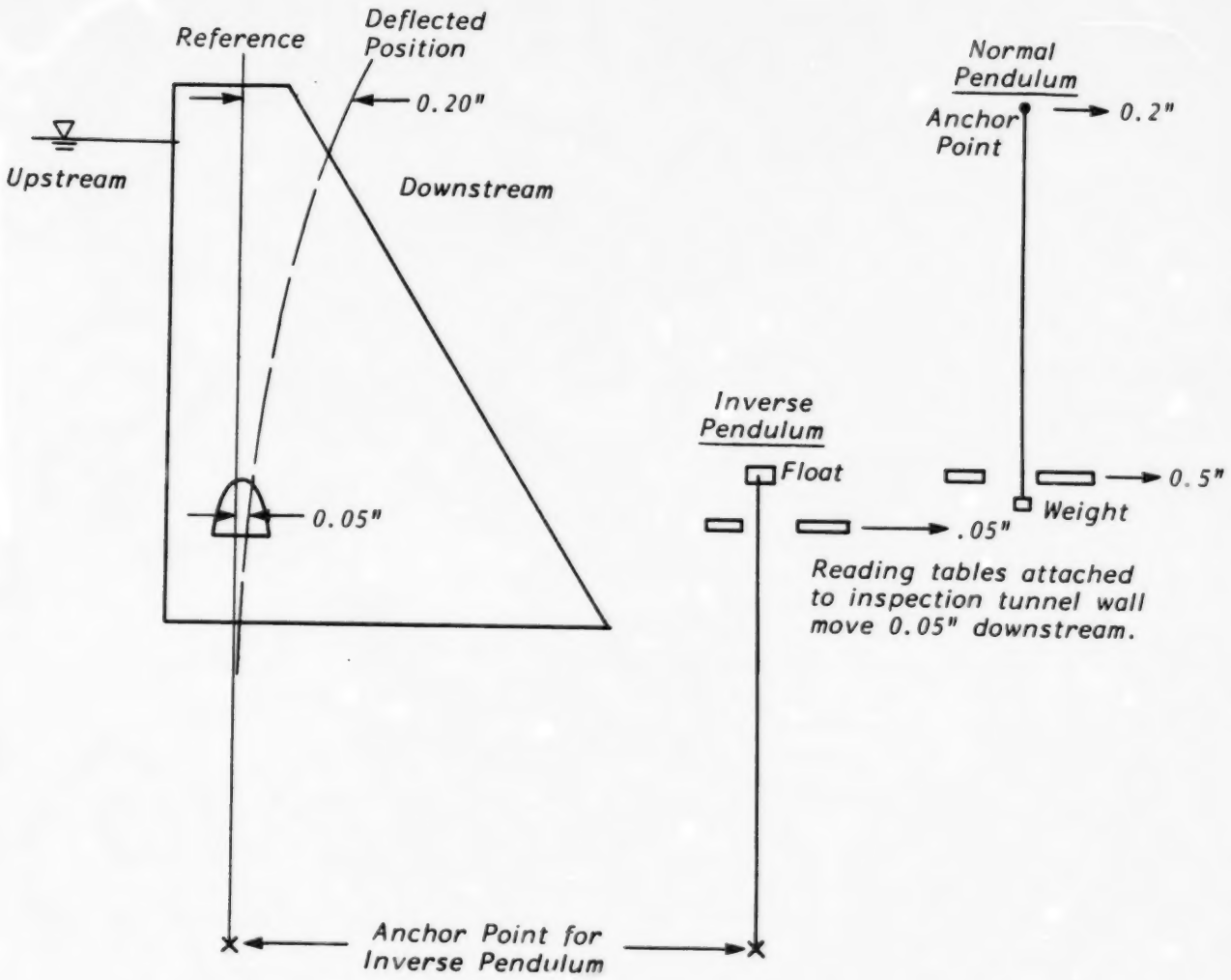
INTRODUCTION

Pendulums detect changes in the relative positions of the reading table and the anchoring point for the pendulum and invar wires. The invar pendulum is assumed to give an absolute measure of deflection because its anchoring point is assumed to be deep enough below the dam that it does not move with the dam. Readings on the normal pendulum are indicative of relative changes only. By combining the readings of an inverse and normal pendulum, when these are located in close proximity, an absolute measure of dam crest deflection can be obtained. Interpretation of the readings can distinguish between cyclical recoverable movements, such as thermal expansion/contraction, and permanent deformations, such as sliding or tilting.

INTERPRETATION

Ideally, the reading tables for the inverse and normal pendulum are located near each other and attached to the same block, so they may be assumed to move together. Having made this assumption one can "sum" the movements of the normal and inverse pendulums to calculate movement of the dam deck. As shown in Figure B1, the two pendulums may appear to be moving in opposite directions, so the sign of the inverse pendulum movement must be changed to properly sum movement for the dam deck level. The apparent contradicting movement results from the different relative positions of the anchoring points to the reading tables. The pendulum wire always remains vertical above or below its anchorage. In the example, the inverse reading table moves downstream relative to the wire, yielding a change in reading which is "upstream". At the same time, the top of the normal pendulum moves downstream, so its wire moves downstream relative to its reading table, yielding a change which is "downstream". From the example figure, it can be seen that these two apparently contradictory readings are consistent. Figure B2 gives examples of instrument responses that may occur if thermal movements, tilting or sliding occur in the dam. Tilting implies movements at the tunnel and deck levels that are in the same ratio as the distances of the tunnel and deck are above the dam foundation. Note that in pure sliding, the normal pendulum reading should not change. No change in the normal pendulum reading should be viewed as seriously as a large change!

Changes in pendulum readings with time should be tracked to check for any long term progressive deformations. A set of allowable or predicted deformations for the dam should be obtained from the structural engineers to determine if the pendulum readings indicate acceptable or unacceptable performance.



Movement Measured

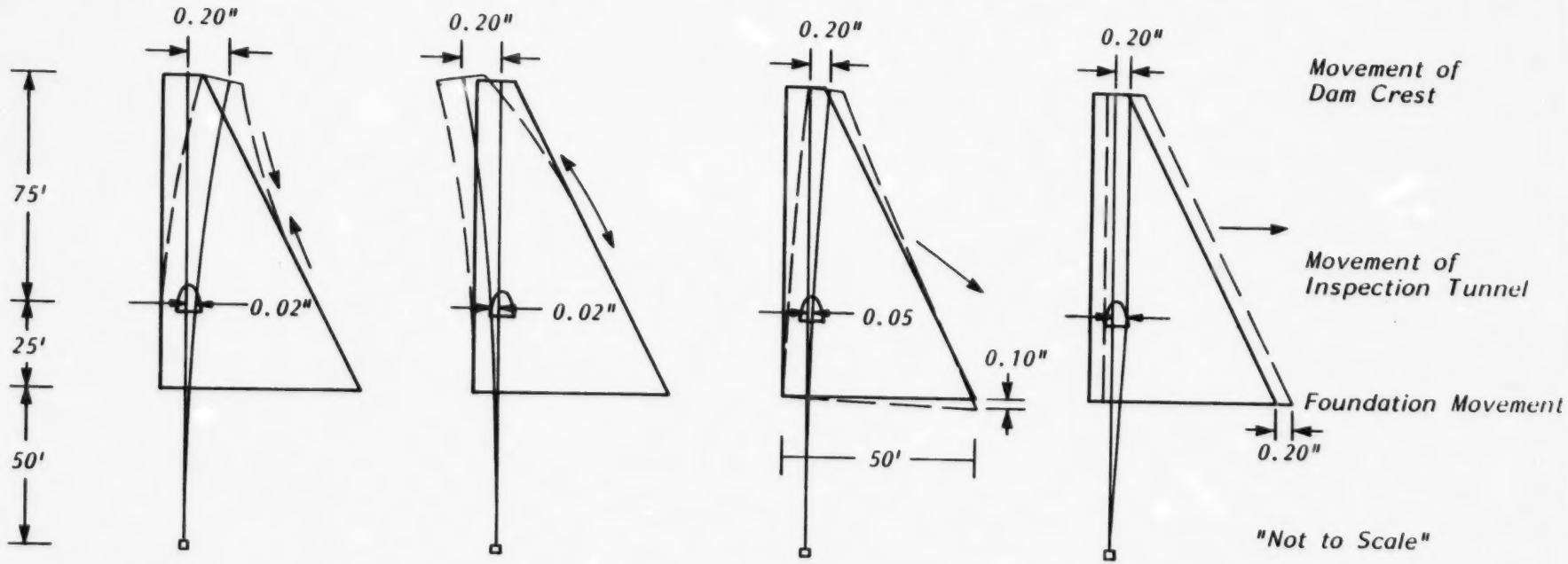
(A) Inverse Pendulum: *Pendulum wire moves 0.05" upstream relative to the reading table.*

(B) Normal Pendulum: *Pendulum wire moves 0.15" downstream relative to the reading table.*

Note: Actual movement of Dam Crest is 0.20" Downstream.

FIGURE B1

EXAMPLE INTERPRETATION OF PENDULUM READINGS



Instrument Response	Winter - Thermal Contraction	Summer - Thermal Expansion	Tilting	Sliding
Normal Pendulum	Move Downstream (.18")	Move Upstream (.18")	Move Downstream (.15")	No Change
Inverse Pendulum	Move Upstream (.02")	Move Downstream (.02")	Move Upstream (.05")	Move Upstream (.20")
Wire Extensometer				
. Normal	Shorten	Lengthen	No Change	No Change
. Inverse	No Change	No Change	Shorten	Lengthen

FIGURE B2

EFFECTS OF DAM MOVEMENT ON PENDULUMS

171936 RD

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